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THESIS

CRITERIA FOR COMBAT READINESS OF COMBAT PILOTS

by

Anestis Hatzipouflis

September 1984

Thesis Advisor:

Douglas E. Neil

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The unique situation of an aircrew flying an aircraft for a specific mission and the necessary determination of subcriteria for evaluating accomplishment of that mission requires further research of an analytical and empirical nature. The relationship among altitude, airspeed, operator activity, and the hundreds of other system variables that comprise the total system must be compared to mission success in quantifiable terms.

This study is an effort to improve acquisition of training performance information in affordable ways on behalf of the Hellenic Air Force (HAF). Thus, it is divided in: (1) The principles of human performance, (2) Definition of the criteria and their measurement, (3) Systematic definition of performance measure appropriate to combat-training needs, (4) Definition of a cost effective measurement system usable in combat-crew training environments to acquire and process needed training information.

The method that was used was a search of the available materials found in the NPS library. Most of the data found was based on USAF studies.

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Criteria for Combat Readiness
of
Combat Pilots

by

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Captain, Hellenic Air Force
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
September 1984

ABSTRACT

Military aircraft missions are all multidimensional in nature. This means that every mission can be divided into usually one overall goal or purpose (i.e., destroy the target, deliver the supplies, rescue the survivors, etc.), with several subgoals (safety, minimize susceptibility, timeliness, etc.). Since missions are multidimensional, the operator effort in the form of mental and physical action (performance) becomes multidimensional. The multidimensional nature of skilled aircrew performance, in turn, requires that several criteria, all of which are relevant for a particular activity, be defined and used [Ref. 1].

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TABLE OF CONTENTS

I.	INTRODUCTION	10
A.	COMBAT READINESS	11
	1. Readiness Categories:	11
B.	CRITERIA AND CONSIDERATIONS	12
	1. Definition and Purpose of Criteria	12
	2. Categories of Criteria	12
	3. Characteristics of Good Criteria	14
C.	HUMAN PERFORMANCE	14
D.	THE PROBLEM	15
II.	PRINCIPLES OF HUMAN PERFORMANCE	16
A.	HUMAN PERFORMANCE REQUIREMENTS	16
B.	FACILITATING HUMAN PERFORMANCE	18
III.	CRITERIA AND THEIR MEASUREMENT	20
A.	USE OF CRITERIA IN PERSONNEL SELECTION AND TRAINING	20
B.	TYPES OF CRITERIA	22
C.	CRITERIA MEASURES	23
IV.	INTRODUCTION TO COMBAT READY CREW PERFORMANCE MEASUREMENT	25
A.	OBJECTIVES	26
	1. Instructional System Development.	26
	2. A Measurement System for the Operational Environment.	27
	3. An Automated Measurement System.	27
B.	MEASUREMENT BASED ON COMBAT-CREW TRAINING INFORMATION NEEDS	28
C.	COMBAT-CREW PERFORMANCE MEASUREMENT	29

V.	DERIVATION OF COMBAT-CREW PERFORMANCE	
	MEASUREMENT.	33
A.	MEASUREMENT COMMONALITY	33
	1. Common Training Phases.	34
	2. Summary of Training Phases.	37
	3. Common Measurement for Maneuvers	38
B.	PROTOTYPE MEASUREMENT.	39
C.	MEASUREMENT PARAMETERS.	42
D.	MEASUREMENT DESCRIPTIONS	50
E.	COMMUNICATION ANALYSIS	52
	1. Communication Measurement Categories.	53
	2. Auditory Data Processing.	54
VI.	CONCLUSIONS AND RECOMMENDATIONS	57
	APPENDIX A: PROTOTYPE MEASUREMENT	60
	LIST OF REFERENCES	64
	INITIAL DISTRIBUTION LIST	67

LIST OF TABLES

1.	Types of Criteria Utilized for Personnel Selection & Training	24
2.	Data Collection Sites	29
3.	Requirements For X-Y Data	35
4.	Parameters for Digital Data Acquisition	49
5.	Parameters for Video/Photo Data Acquisition	51

LIST OF FIGURES

4.1	Example of Prototype Measurement	31
5.1	Identification of Measurement Parameters	44
5.2	Example Raw Data Processing	45
5.3	Example Measurement Specification	46
A.1	Example of Prototype Measurement	61

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I. INTRODUCTION

The Hellenic Air Force (HAF) is interested in optimizing its combat readiness, and consequently the combat readiness of its combat pilots. Greece has common borders with hostile countries and is constantly threatened with possible invasion. There are continuous violations of the aerial and sea space of Greece by neighboring countries' airplanes and ships respectively. We (the Greeks) must offset our numerical inferiority with technology expressed in higher skilled combat pilots. It is imperative to increase to the utmost the combat readiness and effectiveness of the HAF. In this way we shall be a strong power and our enemies will never try to invade our country. Thus, we shall remain in our purpose, that is, united and uninvaded country and most important, because of our power we'll keep the peace.

Today the need for combat effectiveness is more pressing than ever before. We live in a period of rapid and continuous change in technology and consequently in our tactics. The new generation of combat aircraft require more training because of the complexity of the new systems. Because of these technological changes it is required that new changes in air tactics must be established. Thus, because of the above continuous changes, it is required that new criteria for combat readiness of combat pilots must be established (created). Of course, HAF has established criteria for its combat pilots as a result of the entry of the present generation of combat aircraft. However, it may be necessary to see if there are any critical points that need to be corrected or changed. For these reasons this study has been conducted in which the US Air Force was used as a model and a later study will be necessary to adapt these models to the Greek reality.

Thus, this study will define combat readiness, the criteria and their considerations and human performance, in relation to the combat readiness of combat pilots.

A. COMBAT READINESS

But what is combat readiness? In order to answer this question, we first must define the word readiness, secondly combat readiness, and third readiness categories.

Readiness means the quality of being ready to act, respond, comply, etc; Also readiness is a state or fact of being ready, or prepared; as to have everything in readiness for a sudden departure [Ref. 2]. A crew or crew member is combat ready when it is certified as ready for combat [Ref. 3].

1. Readiness Categories:

Combat readiness is expressed with the following standard categories and meanings [Ref. 4].

a. Fully Combat Ready.

A unit fully capable of performing the mission(s) for which it is organized or designed.

b. Substantially Combat Ready.

A unit capable of performing the mission(s) for which it is organized or designed, but having minor deficiencies which could reduce its effectiveness or its ability to conduct sustained operations.

c. Marginally Combat Ready.

A unit with major deficiencies of such magnitude as to severely limit its capability to perform the mission(s) for which it is organized or designed, but

capable of conducting limited operations for a limited period.

d. Not Combat Ready.

A unit not capable of performing the mission(s) for which it is organized or designed.

Definitions of readiness and combat readiness were given above. A classification of combat readiness into four categories was made in an effort to specialize and highlight it. In order to define and understand combat readiness better we have to define criteria and their considerations, that is to say, definition and purpose of criteria, the categories of criteria and characteristics of good criteria.

B. CRITERIA AND CONSIDERATIONS

1. Definition and Purpose of Criteria

Criteria are standards, rules, or tests by which measures of system behavior are evaluated in terms of success or failure, or to some degree of failure. The purpose of human performance criteria is to provide standards or baselines for evaluating the success or failure, goodness or badness, or usefulness of human performance [Ref. 5] and [Ref. 6].

Criteria should not only define the unique manner in which the operator should perform a task, but should define the performance objectives of the entire man-machine system [Ref. 7] and [Ref. 8].

2. Categories of Criteria

The classification of criteria can be accomplished from a measurement standpoint; beginning with the smallest known entity and ending with the "ultimate" quantity that may exist. Several categories identified are listed below:

(1) Parametric referent or standard of performance which is sought to be met by the operator or system. Example: maintain 1000 feet of altitude [Ref. 7] and [Ref. 9].

(2) Parametric limit about the parametric standard within which the operator or system is required, or seeks, to remain. Example: maintain plus or minus 100 feet while at 1000 feet altitude [Ref. 7] and [Ref. 9].

(3) System component criteria which distinguishes the relationship between system components and system output. Example: "least effort" measured from the pilot in relation to maintaining altitude [Ref. 10].

(4) Test criterion used to evaluate overall human ability, usually expressed as a single overall measure. Example: subjective judgement of instructor for a student as to "pass" or "fail".

(5) Ultimate criteria are multidimensional in nature and represent the complete desired end result of a system. This category of criteria is impossible to quantify due to the multidimensional nature of the system's purpose, and hence, is a theoretical entity that must be approximated. Example: Any aircraft's mission [Ref. 1] and [Ref. 11].

It may be noted that all five categories of criteria can be either quantified or approximated in some manner, with decreasing accuracy as the ultimate criteria level is reached.

Obtaining direct measures of the ultimate criteria for a complex system is seldom feasible. This is particularly true in military systems where such criteria would be expressed in terms of combat effectiveness or effectiveness

in preventing a potential aggressor from starting a conflict [Ref. 1].

Therefore, it becomes apparent that we must select intermediate criteria (types (1) through (4) above) in evaluating skilled operator behavior.

3. Characteristics of Good Criteria

Using actual criteria as approximations of the ultimate criteria can be accomplished by several methods that will be presented in the following paragraphs.

Although there is no certain method that will lead to the specification of good criteria, there are some considerations that can be taken into account which are discussed below:

(1) A good criterion is both reliable and relevant [Ref. 1] and [Ref. 10].

(2) Criteria must be comprehensive in that the utility of the individual being evaluated is unambiguously reflected.

(3) Criteria should possess selectivity and have ready applicability [Ref. 10].

Finally, since readiness and criteria are related to human performance, it is necessary to define human performance.

C. HUMAN PERFORMANCE

Much of the data used in human factors consist of measures of some aspect(s) of human performance. Human performance in the context of systems often boils down to consideration of how fast people can perform their functions and how accurately they can perform them. How well functions are performed leads directly to considerations of human errors [Ref. 12].

D. THE PROBLEM

Thus, the problem is the necessity of optimizing the combat readiness of HAF's combat pilots, because of the threatened invasion by neighboring countries. So, we have to identify the necessary variables which will assist the planner (commander) to be certain that his combat pilots will meet the desired level of combat effectiveness in terms of pilot capabilities.

It can be suggested that for HAF the first requirement is to continuously optimize combat readiness. To accomplish this objective it is essential that combat pilots be at an acceptable level of combat readiness. Determination of combat readiness requires definition of concept, specification of criteria and a definition of human performance.

In the chapters to follow an attempt will be made to define and discuss the following: (a) the principles of human performance and (b) the criteria and their measurement. Finally, chapters IV and V will examine combat ready crew performance and derivation of combat-crew performance measurement techniques.

II. PRINCIPLES OF HUMAN PERFORMANCE

A. HUMAN PERFORMANCE REQUIREMENTS

We can best determine performance requirements only after we have a good set of allocated functions. In the absence of function allocation we will have a difficulty identifying and dealing effectively with human performance requirements because we do not know what functions people will be expected to perform.

Once we have established a human performance requirement we should develop a way of measuring it. If the requirement relates to accuracy, then there must be a meaningful way to measure errors. If the requirement concerns manual processing time, there must be a meaningful way to measure it. For example, time per customer contact, number of items produced per hour, and average keystrokes per day.

Usually the problem is deciding what measure gives the best indication of performance. It has been suggested that with a little imagination, any human performance can be meaningfully measured [Ref. 13]. As a minimum, human performance requirements should include statements concerning errors, manual processing time, training time necessary to ensure the minimum skills, and job satisfaction. If we do not clearly state the requirements from the beginning we cannot expect human performance considerations to be taken seriously. And when the system is operational, people will be left to perform as best they can without adequate provision for ensuring an acceptable level of human performance [Ref. 14].

Other human performance requirements could be associated with training time (e.g., total time to train clerical

personnel to perform the basic activities should not exceed three weeks). Another human performance requirement could relate to job satisfaction (e.g., after performing an activity for six months employees should respond in a positive way to their work, as measured by a questionnaire).

The identification of human performance requirements is a prerequisite step for a system's development process. One of the steps of a system's development process is the task analysis. Task analysis is intended to match the work to be done with the kinds of people who will do it. The process has four main parts:

- (1) Determination of a system structure that gives the designer an overall view or objective for the analysis.

- (2) Identification of tasks has essentially nine primary considerations associated with it. These include determining existing knowledge and skills, deriving skill level categories, identifying outputs and inputs, deriving lower level activities, ensuring that activities are mutually exclusive and exhaustive, and matching active complexities with previously determined skill levels. The process may be repeated any number of times until each activity is assigned a single skill level. Secondary considerations in the identification of tasks include meeting the system structure objective just discussed, as well as meeting a full-advantage objective. A designer attempts to develop tasks that will ultimately take full advantage of the user work force. This is difficult to quantify, but during the analysis process, most designers gain a feel for what is meant by taking full advantage of the skills available in their user population and this should be reflected as the tasks are being identified.

- (3) Description of each task and organization of all tasks into a flowchart that will accommodate the variety of different transactions a new system must accomplish.

(4) Identification of work modules that synthesizes the tasks previously identified into manageable modules of work. A human work module is a set of tasks that a user accomplishes as a part or all of his or her job [Ref. 14]. It is a basic unit work. Usually, one or more work modules are combined to form a job.

Having systematically derived work modules assists in the design of interfaces, and the preparation of facilitator materials, such as instructions, performance aids and training.

B. FACILITATING HUMAN PERFORMANCE

Once good work modules are developed, many types of materials can be developed to help ensure an acceptable level of human performance. All of these materials are based on the task analysis results and are usually prepared to support the work module instructions.

Once the designer identifies tasks and determines work modules, he must identify the specific skills and knowledge required for each work module. This amounts to stating his assumptions of the precise qualifications of the person to perform the work module.

As the work modules are designed, the designer should have a set of user characteristics in mind. The design should clearly envision the person performing the work. When this information is written down, it is called a Statement of Minimum Qualifications or SMQ [Ref. 14].

The SMQ is a detailed description of minimum acceptable qualifications in terms of skills and knowledge required to efficiently and effectively perform the work outlined by the work module.

Once the designer has in mind the potential user and has designed the work modules, then he can proceed with developing instructions, performance aids and training.

It is vitally important that human performance considerations begin at least by the time functions are being allocated. Having a good set of human performance requirements is also critical. A systematic and detailed analysis of the tasks to be performed is also very important.

If design considerations are well done, then a strong foundation is established for developing interfaces and facilitators, including Human/Computer dialog structures, instructions, performance aids, training materials.

In this chapter the principles of human performance, namely (a) Human Performance requirements and (b) Facilitating human performance have been discussed.

In order to measure one person's attitude, aptitude and performance we may use criteria. Thus, in the next chapter we shall expand on the concept of criteria and their measurement.

III. CRITERIA AND THEIR MEASUREMENT

As suggested earlier, a criterion is a standard which may be used to evaluate a person's attitude, aptitude, and performance. Since personnel selection and training are important factors for HAF to optimize combat readiness of its combat pilots, we will be concerned with the use of criteria for personnel selection and training purposes.

Selection criteria are described by the degree of correlation between selection test scores and performance measures (in real-world situations), which represent the degree of a pilot's success in performing his job.

Training criteria refer to measures utilized in evaluating the effectiveness of a training program (i.e., the measures that express the degree to which the attainment of the behavioral objectives of the training program have been met) [Ref. 15].

A. USE OF CRITERIA IN PERSONNEL SELECTION AND TRAINING

Personnel selection serves to predict a person's suitability for a job, whereas the purpose of personnel training is to derive a predetermined work standard, or other criterion, in the shortest possible training time. Both purposes can be achieved by analyzing and quantifying the content and skills associated with the job. The validation of each process can be evaluated as follows :

1. The validity of a personnel selection system can be evaluated by the degree of the relationship, or correlation, between test scores against the criteria measures.

2. The validity of a training method can be evaluated by comparing a variety of different training methods with a set of the same criteria for all cases.

The validity of selection and training programs alike is affected by the following factors :

1. The degree to which personnel selection tests or personnel training procedures simulate real-world criteria.

2. The validity of personnel selection tests and training under study.

3. Validity of the criteria considered, true and not merely correlational.

4. Relevance of the criteria considered for (a) the job studied, and (b) the test batteries adopted for selection or training purposes.

5. The stage (initial, ultimate, or rate of learning) at which criteria are measured may affect validities significantly. Typically, criteria measures at the early stages of the acquisition of skill exhibit higher validity coefficients than those we find when the measures are correlated with terminal performance [Ref. 16].

6. Because job performance is multidimensional, taking only one criterion as an index of job performance may result in artificially high or low validity coefficients. Therefore, a multidimensional approach is essential in the measurement of job performance and criteria utilization in personnel selection and training.

7. Evidence indicates that criterion and test measures are typically nonlinear [Ref. 17] [Ref. 18] and [Ref. 19]. Since, moreover, assuming their linearity increases the error variance of the validity coefficient, the validity of the assumption must be tested before linearity is assumed.

8. Fluctuations in an individual's physiological and psychological health condition, need of achievement motivation, and so on, affect the validity coefficient of personnel selection programs as well as training programs.

In summary, it is hardly possible to overstress the importance of a sound criterion measure against which personnel selection and training programs can be evaluated effectively. In order to achieve this objective, emphasis must be placed at the outset on the development of such measures. Without sound criteria the true validity of personnel selection and training cannot be assessed properly.

B. TYPES OF CRITERIA.

Criteria for the purposes of personnel selection and training lie on a continuum scale, which has two interactive dimensions : objectivity-subjectivity and employee-employer satisfaction. Some criteria are entirely subjective; others are entirely objective. Most, however, involve a mixture of the two. In other words we distinguish two types of criteria: (1) Those describing the satisfaction of the employee's needs and (2) those describing the satisfaction of employers in their employees.

The ideal criterion, although rarely found in industry, is the one that reflects the satisfaction of employee's needs as well as that of employers'. A criterion like this is used more frequently for personnel guidance purposes than in personnel selection and training [Ref. 20].

It is essential to aim at using the most appropriate criterion for a specific job, rather than the most convenient criterion, but it is not always feasible to assess the former or to obtain data on it. Thus, the analyst is frequently faced with the practical issue of using the most appropriate criterion which data are available or can easily be collected.

The reason for using a criterion varies since occupational jobs are different; consequently, a variety of

criterion measures have been developed and used during the last century, each with its characteristic weaknesses and strengths. However, any criterion could be the most appropriate for a specific job, depending on circumstances and purpose. The majority of the criteria relevant to today's occupational circumstances and competence are listed in Table 1.

For some of the criteria mentioned in Table 1, objective data can be gathered (e.g., length of employee's service), others require subjective assessment (e.g., rating or ranking by supervisor, subordinates, members of equal status, and the employee himself). For some criteria (e.g., quality of output) both subjective and objective techniques can be utilized. Many of these can be related to training progress at the following stages: (a) immediate, at the beginning of training; (b) intermediate, at the end of training; (c) ultimate, in real-world operations, after completion of training.

C. CRITERIA MEASURES

There are basically three types of methods by means of which criteria data can be collected :

1. Rating or ranking.
2. Counting (e.g., the number of items produced, the number of accidents, the duration of service).
3. Establishing work standards [Ref. 21].

In this chapter we have seen the criteria and their measurement and specifically (a) Use of criteria in personnel selection and training, (b) Types of criteria and (c) Criteria measures. Next we shall introduce the combat ready crew performance measurement.

TABLE 1

Types of Criteria Utilized for Personnel Selection & Training

- I. Criteria reflecting employees' competence
 - A. Quality of performance
 - 1. Quality of output
 - 2. Spoiled work:
 - (a) amount
 - (b) cost
 - 3. Accidents:
 - (a) number
 - (b) cost (financial and human)
 - 4. Breakages (tools, etc.):
 - (a) number
 - (b) cost
 - 5. Mistakes in operation:
 - (a) number
 - (b) cost
 - 6. Variability in performance
 - *7. Rate of advancement
 - *8. Standard trade examinations
 - *9. Training:
 - (a) cost
 - (i) to employer, (ii) to employees
 - (b) duration
 - B. Quantity of performance
 - 1. Quantity of output
 - 2. Earnings on a commission basis
 - 3. Earned bonus
 - 4. Peak performance
 - 5. Lowest performance
 - *6. Rate of advancement
 - *7. Standard trade examinations
 - *8. Training:
 - (a) cost
 - (i) to employer, (ii) to employees
 - (b) duration
- II. Criteria reflecting employees' circumstances
 - 1. Length of service
 - 2. Labor turnover
 - 3. Lateness (categorized according to how late):
 - (a) numbers
 - (b) cost
 - 4. Absenteeism:
 - (a) certified
 - (i) number, (ii) cost
 - (b) uncertified
 - (i) number, (ii) cost
- III. Criteria reflecting employee's satisfaction from job
 - 1. Rating of employee's liking for his present job
 - 2. Rating of employee's satisfaction with job content and desire for job enlargement or job simplification

* Starred items may reflect quality and/or quantity of performance. Since their relationship to performance is indirect, they are less valuable and important than the others.

IV. INTRODUCTION TO COMBAT READY CREW PERFORMANCE MEASUREMENT

Recently, the evaluation of aircrew proficiency in skills associated with advanced flying training was primarily based upon the subjective judgement of instructor pilots. In addition these evaluations are supplemented by the more or less objective scores of gunnery and bombing. In certain areas, such as air combat maneuvering and combat-readiness determination the evaluations are totally objective.

Although, efforts have been made to measure objectively the behavioral skills in the operational and/or crew training setting in an economical way, these efforts have not yet produced any positive results.

A great percentage of the HAF's budget is absorbed by the aircrew training costs, therefore, this area has become of fiscal concern. Due to the projected increase in costs of operating the newer weapons systems over the present generation of combat aircraft the HAF's interest in the problem has intensified in recent years. Studies to minimize costs have shown that this can be achieved by reducing the training flying hours and transfer them (when/where this is possible) to lower cost devices, e.g. simulators.

The HAF is trying to adapt modern Systems Approach to Training techniques to aircrew training programs. Existent in the Systems Approach to Training concept is student advancement on individual proficiency rather than course length. The traditional subjective methods of evaluation may be proved insufficient for the more complex aircrew training objectives.

A. OBJECTIVES

Necessity of improving training performance information of HAF's pilots, directed this study to the following objective based on experiments and studies of USAF [Ref. 22] :

Goal: Systematic definition of performance measures appropriate to combat-crew training needs. Performance measures will include formal statements of methods of measuring flight crew performance used during and at the end of combat-crew training, and, new measures meaningful to combat-crew training and useful as tools for training research.

This study thus is an effort to describe usable measurement tools for utilization in combat-crew training research.

1. Instructional System Development.

Research studies directed toward performance measurement in combat-crew training are highly relevant today in view of USAF policy to employ a systems approach to flying training problems. The model for Instructional System Development (cf., Dept. of Air Force, 1970) contains the following basic steps:

1. Analyze system requirements.
2. Define education or training requirements.
3. Develop objectives and tests.
4. Plan, develop, and validate instruction.
5. Conduct and evaluate instruction.

In support of instructional system development, measures and a measurement system are necessary to:
(1) perform analyses of systems in their operational

environments, (2) establish quantitative instructional standards, (3) provide an index of achievement for each behavioral objective, and (4) evaluate alternative instructional content, approaches, and training devices.

In particular, instructional system development requires that performance standards are identified so that the most efficient approach is used to train the needed skills and knowledge to the desired level of performance. Such performance standards imply performance measurement for both the determination of desirable approaches to training and for testing student performance.

All these events mentioned above should be considered positive and therefore this model for instructional system development could also be used and adapted by HAF.

2. A Measurement System for the Operational Environment.

It will be necessary to develop measurement tools that would be usable in the operational environment of HAF under the constraints that such an environment implies. Within the context of this requirement, it is essential that an attempt be made to establish a list of parameters to be sensed, and the point-of-view taken that the parameters should be derived from that information that the operational training personnel consider to be meaningful and significant.

3. An Automated Measurement System.

An ancillary objective is to develop a measurement system that will relieve the instructor pilot, to a maximum extent, from the requirement of having to record a great deal of information manually on the basis that such activity

degrades his ability to competently instruct his student. This does not imply that such a measurement system is an attempt at automated evaluation. The measurement system should certainly include means for transforming and analyzing performance information, but ultimately evaluation and decision for training control is a human function.

Thus, HAF would improve and optimize the quality of training of its combat pilots by adapting an instructional system development, a measurement system for the operational environment and finally an automated measurement system.

B. MEASUREMENT BASED ON COMBAT-CREW TRAINING INFORMATION NEEDS

The strategy employed by the USAF was to design a measurement system that could acquire that data identified as meaningful by training management and instructor personnel. Data were gathered from sites across a broad spectrum of combat-crew training programs of USAF.

The combat-crew training sites from which data were taken are listed in Table 2. The aircraft sample included heavy (inter- and intra-theatre cargo/transport, and bomber) and high-performance aircraft (one- and two-man interceptor and tactical fighter). An attempt was made to (1) consider measurement in the context of combat-crew training, (2) assess measurement already included as well as identify potential measurement indicated by combat-crew training personnel, and (3) assess the constraints placed by the environment on feasible, usable measurement systems.

From the six types of aircraft listed in Table 2 the HAF pilots fly the three of them, that is F-4E, C-130E and A-7D. Thus, the USAF's attempt and data found are of great interest for HAF, in order to improve training performance information for its combat-crews.

TABLE 2
Data Collection Sites

<u>Place</u>	<u>Aircraft</u>
Castle AFB	B-52 F, G & H
Altus AFB	C-141A
Dyess AFB	C-130E
Davis-Monthan AFB	F-4 C, D & E
Tyndall AFB	F-106 A & B
Luke AFB	A-7D
*George AFB	F-4E
*Norton AFB	C-141A
**Nellis AFB	F-4E

* Special emphasis on crew-performance measurement
 ** Special emphasis on air-combat maneuvers performance measurement.

C. COMBAT-CREW PERFORMANCE MEASUREMENT

For the six aircraft mentioned in Table 2, a common basis for measurement was established. This way it could be possible to apply a more or less modular approach. Allowance must be made for special aircraft characteristics; for example, the F-106 has no flaps and the B-52 has a quite complicated flap retraction routine compared to other aircraft. Measurement was treated for each of the following maneuvers:

- (1) Takeoff and Climb
- (2) Pattern, Land and Go-Around
- (3) Instruments
- (4) Formation
- (5) Air-Air Intercept

- (6) Air Combat Maneuvers
- (7) Air Refueling
- (8) Ground Attack
- (9) Air Drop and Air Drop Formation
- (10) Radar Navigation and Bombing.

Prototype measurement. For each of above maneuvers, the data collected from the sites of Table 2 were compiled into the summary form shown in Figure 4.1 Since the blanks in the summary form of Figure 4.1 indicate needed information, and consequently items for measurement development, these forms were termed Prototype Measurement since they form a model after which measurement could be patterned. Details and explanations of a prototype measurement is presented in Appendix A.

Measurement Specifications. The parameters which must be sensed to permit measurement are not immediately evident from the information requirements (Prototype Measurement), since the measure specifies the output of a computation, and the computation itself must be known before the inputs to the computation (the parameters) can be determined.

For example, Figure 4.1 indicates that a measure of centerline deviations is desired during the takeoff roll. It is clear that the distance between the aircraft position on the runway and the runway centerline is a parameter needed for measurement. The desired measurement might be simply the average difference, or, conceivably, might involve the relationship between centerline deviation and heading (or lateral-G, or brake application) and thereby indicate the need for other parameters to execute the calculations for measurement. Further, the measurement calculations must be made (as indicated in Figure 4.1) from the application of takeoff power until rotation, implying the need for other

TAKEOFF & CLIMB*

CONDITIONS:

Gross Wt:____ Wing:____/ Runway:____/ Temp.:____ Alt. Set.:____ Field Elev.:____ Form Pos.:____

TAKEOFF ROLL: (To power until rotation)

Power Set:____ Centerline Dev.: Min, Max, Av.
Reject Speed: Computed Heading: Min, Max, Av.
Time:____ Dist:____ Bank: R Max, L Max

ROTATION: (Nose gear off until pitch att. established)

Rot. Speed:____ Stab. Trim:____
Pitch: Rate:____ Bank:____
Final:____ Centerline Dev.:____
Overshoot:____ Heading:____

LIFTOFF: (Pos. Vert. Vel.)

Airspeed:____ Pitch:____ Bank:____ Hdg:____
Vert. Vel. After:____ Sec.:____

GEAR-UP: (Handle up until gear-up & locked)

Gear-Up Speed:____ V.V. Init.:____ V.V. Final:____
Pitch:____ Bank:____ Hdg:____

FLAPS UP: (Start up to full up) **

Trim:	B-52	On Iy	IAS	PITCH	ALT	VV	TRIM
Pitch:--	Bank:	Hdg:--	Start	x	x	x	x
A/S (INIT)--	{FINAL}--	1st Pos	x	x	x	x	x
VV (INIT)--	{FINAL}--	2nd Pos	x	x	x	x	x
ALT (INIT)--	{FINAL}--	Full	x	x	x	x	x

CLIMB & LEVEL OFF: (Depends on Flight Plan)

	PWR	A/S	MACH	INIT HDG	INIT ALT	FINAL ALT	PITCH	TRIM
Accelerate	x	x	x	x	x	x	x	x
Climb A/S {#1}								
Climb MACH {#2}	x	x	x	x	x	x	x	x
Level-off {Alt-10% VV}								
{to Cruise}	x	x	x	x	x	x	x	x

* Also, mandatory communication & instances where A/C limits are exceeded.

**F-106 has no flaps

Figure 4.1 Example of Prototype Measurement.

parameters to indicate when the measurement interval starts and stops.

Since the pilots of HAF fly at most the same aircraft¹ as USAF pilots, the data gathered from these USAF bases are of great interest for HAF. Of course, of greatest interest are the data of the three similar aircraft (F-4E, A-7D, and C-130E), but the data related to the other aircraft should also be of great interest. These may be applied to other aircraft that pilots of HAF fly (e.g. F-1C Mirage, or F-5A/B), or aircraft that HAF will be procured in the near future.

¹The aircraft that the HAF's pilots fly and are similar to the USAF aircraft bases from where data were gathered are: F-4E, A-7D, and C-130E.

V. DERIVATION OF CCMBAT-CREW PERFORMANCE MEASUREMENT.

One of the principal products of the USAF study was the definition of performance measures appropriate to combat-crew training needs. That study was based on interviews with instructors and training management and measurement definitions were evolved in the following steps :

(1) The varied requirements posed by the six aircraft and missions were consolidated into a common framework which permitted isolation of measurement modules (measurement commonality) ;

(2) Discussions of operational training information needs were formalized to indicate in a checklist fashion the measurement development needed (prototype measurement) ;

(3) Measurement parameters and (4) measurement specifications were produced together, but are presented separately for hardware and software implications, respectively ;

(5) Measurement and analysis for crew communications recording were examined to provide means of examining crew interaction and individual contributions to total man-machine system performance.

A. MEASUREMENT COMMONALITY

Common measurement was executed to permit the design of one simple and practical measurement system, and eliminate the need for a totally unique measurement system for each aircraft. This measurement system could apply in HAF.

1. Common Training Phases.

In the USAF program the first step was to compare similar training phases for each aircraft, in order to estimate the commonality measurement requirements, as it is shown in Table 3. In cases where X-Y² data are required for measurement it was found that these data could be obtained by using expensive equipment (such as a multiple-target tracking radar) or with difficult-to-process recordings, while equivalent results could be obtained with video/photo sensors. As we can see in Table 3, almost all cases of X-Y data requirements can be met by using video/photo recording. Those cases where the X-Y data cannot be obtained with video/photo sensors are: (1) lateral drift across the runway during transition, (2) relative position of aircraft during intercept prior to lockon, (3) enroute cross-track error during airdrop, (4) inflight ranging (out of sight) during formation, and (5) space paths of multiple aircraft during air combat maneuvers.

Although, photo-sensors are widely used by the HAF, video is not. So, the use of video films would be recommended because video is a modern technology equipment with many advantages (e.g., film does not need development and therefore can be used immediately after flying during debriefing).

Not all maneuvers were taught at all sites from which data was taken. For example, the operational C-130 squadron did not explicitly train transition maneuvers; nevertheless, competent information was obtained for measurement. Since all combat maneuvers were not taught at the combat-crew training squadrons, they had gaps in data

²The X-Y data are not in the form of a tabulation of X- and Y-values, but they are position information such as the relationship between tanker and refueling aircraft from the tanker lights.

TABLE 3
Requirements For X-Y Data

	<u>Phase</u>	<u>Parameter</u>	<u>Obtainable with Video/Photo?</u>
1	Transition	Ground Track	RA*
2		Centerline Dev	RA
3		Lat. Drift	No
4		Threshold	RA
5		Dist. Down RNWY	RA
6	Intercept (Prior To Lockon)	Spacing	RA
7		TGT. Azimuth	No
8		TGT. Elevation	No
9		TGT. Range	No
10		TGT. Range Rate	No
11	Air Refueling	TGT. Aspect Angle	No
12		Tanker Range	RA
13		Tanker Range Rate	RA
14		Centerline Displ.	Yes
15		Lights Up	Yes**
16		Lights Down	Yes**
17		Lights Fore	Yes**
18		Lights Aft	Yes**
19		Altitude Error	RA
20	Air Drop	Cross Track Error	No
21		Position Error	Yes
22		Range from Lead	RA
23		Bearing from Lead	RA
24		Δ Altitude from Lead	RA
25	Formation	Actual Air Release Pt.	Yes
26		Range	RA
27		Range Rate	RA
28	Ground Attack	Bearing	RA
29		TGT. Slant Range	RA
30		Aim Point Error	Yes
31		Bomb Fall Line	Yes
32		Flight Path	RA
33		Spacing	RA
34	Dart Firing	Range	RA
35		Azimuth	RA
36	Air Combat	Elevation	Yes
37		TGT. Range	RA
38		TGT. Range Rate	RA
39		TGT. Aspect Angle	RA
40		TGT. HDG Cross Angle	No
41		Elevation	RA
42		Space Path	No

* RA=Reduced Accuracy
 **Obtainable with Video/Photo System,
 but not easily otherwise.

collection. They tried to fill these gaps by cross-checking, where possible, with other aircraft training.

The following are observations of the degree of commonality of training phases for the six USAF aircraft and HAF's aircraft also:

(1) TRANSITION (TR). Transition is a phase of combat-crew training. Transition maneuvers appear in a common fashion, but the manner in which they are performed is significantly different for different aircraft. This phase has been already adapted by HAF.

(2) INSTRUMENTS (INST). Instruments is a common flight phase for all aircraft (also adapted by HAF) and consequently common measurement (criteria) is conceptually possible.

(3) FORMATION (FORM). Formation flight is performed by all six aircraft as a means to optimally employ composite flight and provide individual-ship effectiveness. It is considered as a common flight phase among all aircraft, however, a number of types of formation exist for specialized missions, each appropriate only to specific aircraft. The formation phase is widely used in HAF by high performance aircraft (as in F-4E, A-7D, F-1C, F-5A/B) and is very limited among multi-engine aircraft (C-130, DC-6, Albatros). Measurement differences will occur between the categories of high performance aircraft and multi-engine heavy aircraft.

(4) AIR-AIR INTERCEPT (AA). Air-to-air intercept and weapons delivery utilizing airborne radar is accomplished with only the F-4 and F-106 aircraft (in HAF with F-4E and F-1C). While the F-4, F-1C and F-106 maneuvers and equipment differ, the same basic measurement requirements are presented. Almost the same basic measurement requirements could also apply in F-5A/B of HAF, against the event that air-air intercept is accomplished by ground radar.

(5) BASIC FLIGHT MANEUVERS (BFM) AND AIR COMBAT MANEUVERS (ACM). BFM and ACM are grouped together in F-4 training, and could be grouped also in F-5A/B and F-1C of HAF, while BFM and Formation are grouped together in A-7 training. The BFM/ACM grouping was maintained for purposes of measurement problem.

(6) AIR REFUELING (AR). Air refueling can occur with four of the six USAF aircraft (B-52, F-106, F-4, A-7), but is only considered a difficult maneuver for the B-52. In HAF air refueling can occur only in F-4E and A-7 but is not used since there are not any tankers available.

(7) GROUND ATTACK (GA) AND DROP. A number of training phases are devoted to F-4 and A-7 (both aircraft are available by HAF) ground attack (Day, Tactical, Night, with various weapons and delivery modes), but common measurement was judged to be appropriate.

Air Drop (combat airlift mission) maneuvers for C-141 and C-130 training perhaps superficially resemble level-flight ground attack, but quite different measurements are posed. Ground attack and drop phases have been also adapted by HAF but in this case the measurement is different.

(8) RADAR NAVIGATION AND BOMBING (RNB). Navigation by use of radar, and subsequent delivery on target of either ordnance or cargo, occurs with most of the aircraft of the sample except the F-106, and compatible mission performance measurement is indicated. In HAF this phase is used by all aircraft except these that are not equipped with radar (e.g., F-5A/B).

2. Summary of Training Phases.

The examination of the USAF study shows that measurement (criteria), for the training phases of the sample of six USAF aircraft, are composed as follows :

Transition

Instruments

Formation
Air-to-air Intercept
Air Combat
Air Refueling
Ground Attack
Air Drop
Radar Navigation and Bombing

All of these training phases (except air refueling) are widely used by the aircraft of HAF. From both studies, USAF's and present, it is concluded that not all of the training phases are applicable to all types of aircraft. For this reason, it is required to ignore the measurement developed in cases where a specific phase could not be applied.

3. Common Measurement for Maneuvers

Each phase of flight, tentatively considered to permit common measurement, was examined for detailed measurement requirements. All needed measurements, for each maneuver used in the USAF study, were provided by (1) interview notes with Instructors and Training Managers, (2) Aircraft Technical Orders, Dash-one flight manuals for each aircraft, (3) Phase Manuals, (4) Instructor Guides, and (5) other specialized documents. Important information, as judging factors and common errors were noted for each maneuver, along with other important remarks that an instructor pilot, or training manager, would consider and thus translated into objective measurement.

For example, measurement requirements were noted for each aircraft during takeoff and climb-out maneuvers (Runway Roll, Rotation, Liftoff, Gear-up, Flaps-up, Climb and Level-off). A matrix of measurement requirements was thus produced, allowing comparison across aircraft. It was noted that takeoff and climb-out are essentially the same for all

aircraft, with the exception of the importance of some maneuvers (e.g., rotation is critical with the F-106), variations in aircraft design (e.g., F-106 has no flaps, B-52 involves a complicated flap schedule), and climb profiles depend on the specific mission and clearance.

Although there were some differences, in measurement requirements among different types of aircraft, the similarities proved to be a lot more. Also, a modular approach to measurement was suggested, that is, measurement could be produced by examining every maneuver in sequence for every type of aircraft.

All of the above mentioned maneuvers are used by the Hellenic aircraft and thus common measurement for maneuvers in a modular approach could also be considered by all aircraft.

B. PROTOTYPE MEASUREMENT.

After the examination of measurement commonality of training phases and maneuvers, the USAF study developed, in the form of formatted measurement outputs, examples of the required information for training. That is, if a measure of centerline deviation was indicated to be desirable, this would be noted. In this way they recorded all of the known information requirements for a given phase of flight, and then, they formed the data found into a format to resemble measurement output. This output is termed here as Prototype Measurement.

An example of prototype measurement is displayed in Figure 4.1 for takeoff and climb. Details and explanations of this (prototype measurement) example is presented in Appendix A. A blank or x in Figure 4.1 indicates one or more numerical entries to be determined as a result of measurement. For every one of the training phases similar measurement was developed.

In the USAF study the prototype measurement was produced for the following training phases:

(1) TRANSITION. For convenience, transition was divided into (a) Takeoff and Climb, and (b) Pattern, Land or Go-around. As previously noted, measurement appropriate to the composite of six aircraft is indicated; the F-106 and B-52 require special treatment.

(2) INSTRUMENTS. Measurement for instrument flight is treated as the sum of (a) basic aircraft control performance, and (b) navigation performance with respect to air traffic control requirements. While required measurement modules for each of these classes of measures can be specified, it is difficult to present detailed measurement except for specific clearances and published procedures.

(3) FORMATION. Measurement for formation flight is super-imposed onto mission performance measurement, thus making formation measurement difficult to isolate. In particular, tactical formation performance was not clearly identified in this study in an objective quantitative fashion. It may be necessary to rely heavily on instructor subjective measurement (which may be quite satisfactory when the instructor is in a position to observe performance), except for measurement associated with join-up, close formation, and in-trail formation.

(4) INTERCEPT. In order to be specific, intercept measurement was based primarily on the F-106, however, the intercept problem is essentially the same as the F-4. Of course, a two-man crew performance is expected to be better in the F-4. There is a radar observer to perform the scope work and differences in the equipment and capability suggest that slightly different strategies might be employed.

(5) AIE COMBAT MANEUVERS. Prototype air combat maneuvering measurement dealt primarily with set-ups during initial training and for dart³ firing.

(a) Air combat set-ups involve placing attacking and defending aircraft in fixed initial positions, then freeing them to perform a maneuver, and subsequently judging from the final position whether the maneuver was properly performed and whether proper advantage of the tactical situation was taken. Thus, measurement can be directed to description of the maneuvers performed (e.g., hard turn, hi-lo-speed yo-yo, scissors, barrel roll, etc.), and to determining whether a given student was able to improve his situation.

(b) For dart firing the prototype measurement assumes a butterfly pattern or the equivalent. A pass is made over the target, a time hack is taken crossing the dart, the pilot must circle back to make an intercept to put a hole within the target in a given amount of time. Thus, the time and hits on each pass is measured; additionally the range, azimuth, and elevation at the beginning and end of firing describe the firing position. Fouls are called for low airspeed and for firing within a minimum firing range.

(6) AIR REFUELING. As Air refueling is especially difficult in E-52 combat-crew training, the prototype measurement was tailored to the E-52 tasks and to Strategic Air Command requirements.

(7) GROUND ATTACK. During training, ground attack is divided into ground attack, ground attack night, ground attack tactical. Ground attack measurement was dictated by information needed for standard error analysis of weapons delivery accuracy and by ground attack procedures. Some of

³The dart is a kind of air to air target, towed by a tow aircraft.

the measures are specially designed to apply to the A-7D heads-up display.

(8) AIR DROP. Extensive prototype measurement was dictated for the Combat Airlift Mission since very detailed procedures are adhered to throughout the many portions of the mission. Crew performance is especially important in this mission.

(9) RADAR NAVIGATION AND BOMBING. Prototype measurement for Radar Navigation and Bombing is heavily dependent on the characteristics of the avionics used. As only the B-52 is equipped with low-level terrain avoidance radar (of the aircraft sampled in this study), measurement for these maneuvers has been tailored to this application.

Of course, from the examination of the prototype measurement we can see that the measurement requirements are very extensive and complex. For example, it may be seen that to describe just Takeoff and Climb, it is necessary to compute 50-100 numbers. Subsequently, if full mission measurement is required, including transition, instruments, formation, and weapons delivery, it will require a very large set of descriptive numbers. But probably, this detail is very necessary to support the training process. The instructor may need considerable detail to perform his job well. As a consequence, the prototype measurement could be very useful for HAF, since today the evaluation of aircrew proficiency in skills associated with advanced flying training is primarily based upon the subjective judgement of instructor pilots.

C. MEASUREMENT PARAMETERS.

Measurement is the process of producing measures which are indices of performance such as the conditions existing at the time of weapon release during ground attack,

deviations from the clearance during IFR flight, and flight conditions at lift off. The measures are commonly computed from flight variables (e.g., altitude, airspeed, heading, etc.) and other raw information which must be recorded at some time; these are termed measurement parameters. The measurement parameters must be specified so that the required sensors and recording equipment can be determined. However, since the measures are the result of a computation, the details of the computation must be known so that the inputs to the computation (the parameters) can be established.

Figure 5.1 depicts the relationship between the specified measures, the computation, and the measurement parameters. The corresponding data processing is shown in Figure 5.2. It is assumed that the flight maneuvers will be divided into segments, so that different measures may be computed as appropriate for each segment (for example, different measures are required during takeoff roll than during climb-out). Consequently, it may be seen that the method of determining when to start and stop the computation of a specific measure may require the recording of measurement parameters in addition to those required during measure computation (e.g., the recording of weight-off-the-wheels to indicate liftoff).

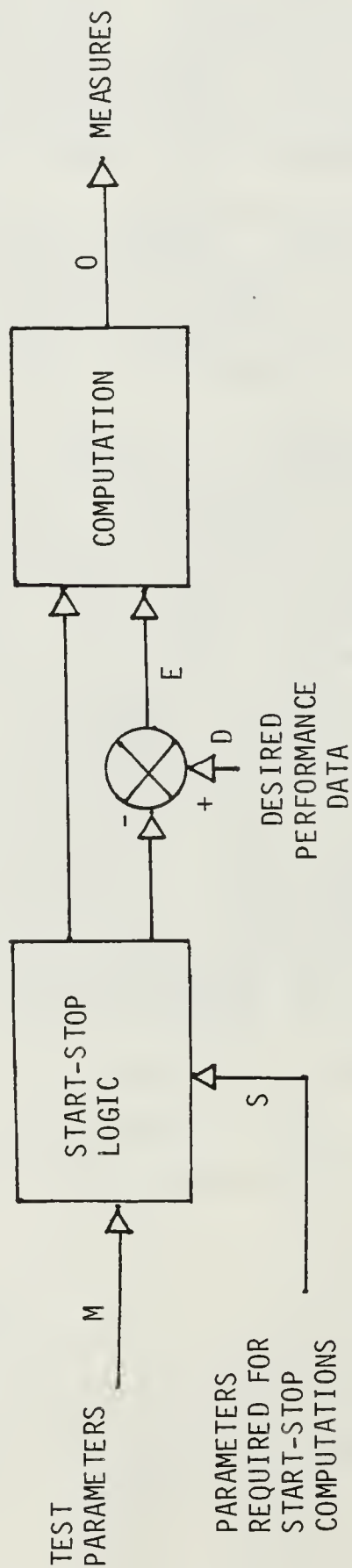


Figure 5.1 Identification of Measurement Parameters

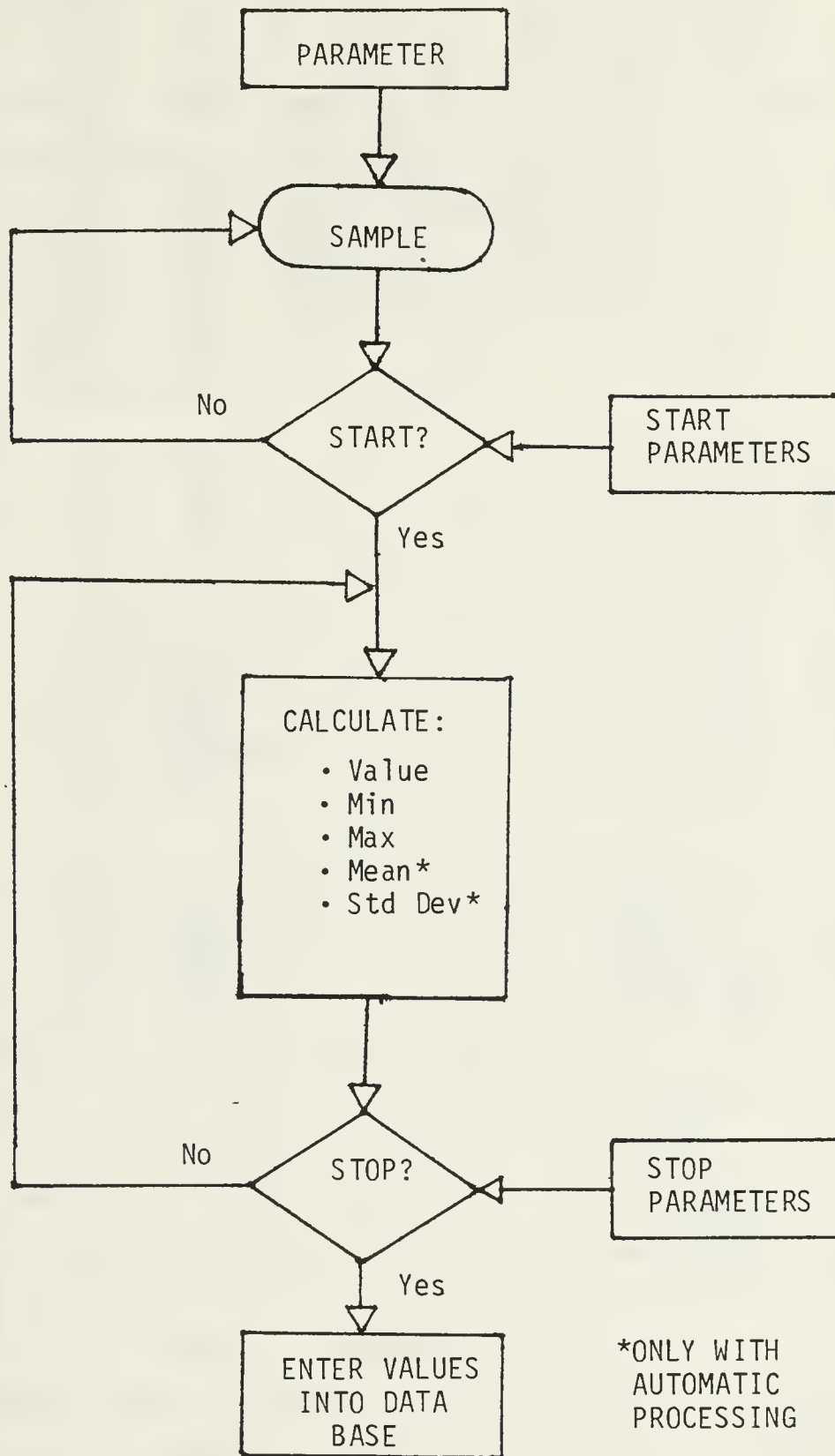


Figure 5.2 Example Raw Data Processing

MANEUVER	MEASURE	FUNCTION	CONDITIONS	COMMENTS
Takeoff	GMT	Value	At Brake release.	
	Power Brakes	Average MC	From Brake Release to Rotation.	Power, Aircraft dependent; Use Fuel Flow, TIT or N ₂ .
	Centerline Deviation	Average Minimum Maximum	From Brake Release to Rotation	Complex Instrumentation - On ILS runways, use localizer deviation corrected for range. Range either ILS/DME or approximation using the integral of airspeed. - TACAN accuracy probably not sufficient. - Windscreen, HUD, Photography possible source with rotation. - Good inertial (commercial quality) also possible source.
	Heading	Average Minimum Maximum	Error from rnwy heading from brake release to Rotation.	Insertion of rnwy heading required in processing.
	Roll	Minimum Maximum	From Brake Release to Rotation.	Looking for maximum left and maximum right roll attitude.

Figure 5.3 Example Measurement Specification.

In Figure 5.1, the output measures (O) correspond to the information requirements symbolized by the blanks in the prototype measurement forms; that is, if the prototype measurement forms indicated that a measure of centerline deviation is needed, then parameters must be recorded and computations developed which will answer the required measure, the following types of parameters may be needed in addition to the basic test parameters (M) (for example just mentioned, the basic test parameter would be a recording of the deviation from the runway centerline during takeoff roll): (1) parameters for implementing logic to start and stop measurement computations (S), (2) information related to desired performance (D), and (3) error information derived from the differences between actual and desired performance (E). In short, given output measures (O), to determine other parameters which must be sensed (M,S,D,E), it is necessary to determine logic and computations to be used in measurement data processing (i.e., the measurement algorithms).

Assuming automated measurement, i.e., parameters are automatically recorded for subsequent computer analysis, the primary details of measurement computation (Figure 5.2 shows a representative flow diagram) are presented in Figure 5.3 for each maneuver and maneuver segment of combat-crew training phases. The figure 5.3 indicates the name of each measure, the specific function to be computed, and the start/stop conditions for controlling computation. For example, centerline deviation during the takeoff roll is desired output information, the average, minimum and maximum deviation are the specific computations which should be performed between brake release and rotation. Comments are also provided as considered appropriate by the analyst to point up alternatives, or where problems may be encountered during design.

Since figure 5.3 indicates the functions to be computed, the conditions under which computation should occur, and indirectly the source information upon which to base computation, the basic information is provided to allow preparation of computer programs for automatic measurement.

When a list of parameters was developed to show all the required sensors and recording needed for total measurement, it was seen that the resulting parameters could be placed in the following overlapping categories: (1) pictorial information (e.g., out-the-window radar), (2) analog information (e.g., time-varying quantitative, such as airspeed), (3) discrete information (e.g., weapon release), (4) audio information (e.g., communications), and (5) desired performance and existing conditions. These parameters were later assigned to alternative devices for data acquisition. After tradeoff analyses were conducted, a hybrid audio-video/photo-digital recording system was adopted. Although many parameters could be acquired by either video-photo or digital recording devices (to allow a partial system to have a stand-alone capability), tentative parameter allocations are listed in Tables 4 and 5. Audio recording will be accomplished with either video-photo or digital recording devices. Desired performance and conditions are manually derived from briefing/debriefing sessions and documents. Additionally, spatial coordinates (X-Y data) may be obtained if data are collected on an instrumented range including tracking-radar equipment, although equivalent information may be available from video-photo recording as shown in Table 3.

After detailed trade-off analyses, the use of video or photo techniques was emphasized due to lower costs, flexibility of application and simpler development compared to other all-electronic techniques; however, the problems associated with cockpit installation and an unfortunate tendency

TABLE 4
Parameters for Digital Data Acquisition

	T R A N S M I T T I O N	I N S T R U M E N T S	F O R M A T I O N	I N T E R C E P T	A I R R E F U E L	A I R D R O P	G R O U N D A T T A C K	D A R T F I R E	A I R C O M B A T	A C C U R A C Y
<u>AIRCRAFT PARAMETERS</u>										
1. Pitch (Pitch Rate)	x	x		x		x	x	x	x	±1 degree
2. Roll	x	x		x		x	x	x	x	±1 degree
3. Heading	x	x	x	x		x	x	x	x	±1 degree
4. Airspeed	x	x	x		x	x	x	x	x	±1 knot
5. MACH	x			x					x	±.02 MACH
6. Altitude	x	x		x	x	x	x	x	x	±10 feet
7. Vert. Vel.	x	x		x	x	x	x	x	x	±50 fpm
8. Angle of Attack	x	x		x			x		x	±1 unit
9. Acceleration (G),	x			x			x		x	±.5G
10. Power (RPM, EPR, TIT, Fuel, Flow)	x	x		x	x	x	x	x	x	±1% Full Scale
11. Fuel Quantity				x	x				x	±5% Full Scale
<u>CONTROL PARAMETERS</u>										
1. Stick (Pitch)			x		x				x	±5% Full Scale
2. Stick (Roll)			x		x				x	±5% Full Scale
3. Rudder									x	±5% Full Scale
4. Flap Position	x					x			x	±5% Full Scale
5. Stab Trim Position	x		x		x					±5% Full Scale
<u>BINARY DISCRETE PARAMETERS</u>										
1. Thrust Reverse	x									--
2. Speed Brakes	x	x			x				x	--
3,4. Main, Nose Gear Contact	x									--
5. Nose Steer Engaged	x									--
6. Gear Select	x									--
7. Drag Chute	x									--
8. Wheel Brakes	x					x				--
9,10. Red, Green Light						x				--
11. Weapon Release (Pickle)			x				x	x	x	--
12,16. Crewmember Voice Switch	x	x	x	x	x	x	x	x	x	--
17,19. Marker Beacon		x								--
20,24. Event Marker	x	x	x	x	x	x	x	x	x	--
<u>TIME</u>										
1. GMT (Range Time)	x	x	x	x	x	x	x	x	x	Hrs, Min, Sec, 1/100 Sec.

for loss of data should be noted, but it is believed necessary to accept these deficiencies for low-cost combat-crew training application.

Accuracy requirements for measurement parameter sensing and recording are listed at the right-hand side of Table 4. These accuracies are referenced to the information displayed to the crew (for example, the required airspeed tolerance is plus or minus 1% of the deviation between recorded values and those displayed to the pilot on his airspeed indicator) since the criterion given the crew is that they maintain vehicle parameters within specified tolerances referenced to their instruments (typically 5-10 knots for airspeed control). The tolerances listed in Table 4 are approximately 1/10th the tolerances required of the crew.

As a result, (a) if HAF has to make a choice between video/photo and digital recording approaches to measurement system design, then the video/photo recording would be chosen for cost, information provided, flexibility and ease of use. (b) A hybrid system combining the advantages of both is preferable to either type of recording alone. Due primarily to cost, the bulk of measurement parameters would be derived from a video/photo system, and the remainder with a small digital recording capability.

D. MEASUREMENT DESCRIPTIONS

The gross operations involved in measurement computation are presented in the flow diagram in Figure 5.2 Each parameter must be sampled (at a sampling rate of 2, 10 or 20 times a second, depending on the application) and tested to determine if conditions are appropriate to start measurement computation, and later to stop computation. During the measurement interval (or at specific conditions, e.g., flaps-up), one of the following statistics is calculated:

TABLE 5
Parameters for Video/Photo Data Acquisition

PHASE	PARAMETERS
Transition	Runway Centerline Deviation, Lateral Drift, Threshold Crossing, Distance Down Runway, Ground Track.
Instruments	TACAN (Frequ., Course Set, Course Error, Bearing, DME); VOR (Frequ., Course Set, Course Error, Bearing); ILS (Frequ., Localizer Error, Glide Slope Error, Marker Beacon).
Intercept	Target use of ECM, Maneuvering Radar: Azimuth, Elevation, Range, Range Rate, Range Gate, Steering Dot Error, Firing Circle Radius, Lockon Pulse, IF Gain, Video Gain, Erase Intensity.
Refueling	Range to Tanker, Range Rate, Probe Engagement, Centerline Displacement, Lights (Up, Down, Fore, Aft), Attitude Error.
Air Drop	Crosstrack Error, Groundspeed, Terrain Clearance, Range/Bearing/ Δ Altitude from Lead A/C, Red/Green Drop Lights, Actual Air Release Point.
Formation	Spacing: Range, Range Rate, Bearing, Δ Altitude.
Ground Attack	Target Slant Range, Aim Point Error, Bomb Fall Line, Flight Path Error, Spacing in Range Pattern.
Dart Firing	Range, Azimuth, Elevation, Hits.
Air Combat Maneuvers	Target Range, Range Rate, Aspect Angle, Heading Crossing Angle, Elevation.

(1) the value of a parameter, (2) minimum value, (3) maximum value, (4) mean, or (5) standard deviation. Thus, measurement is defined by specifying start/stop conditions and one of the five statistics.

An example of a measurement specification patterned in this fashion is shown in Figure 5.3. Measurement specifications were produced for each common training phase.

While these specifications initially assume automatic recording and computation, they can also be used to describe manual data processing (e.g., a discrete signal indicating wheels-up). These parameters can also be used to start and stop manual processing such as scanning for out-of-tolerance conditions. During the measurement interval, the value, minimum or maximum of a parameter may be determined manually, but manual processing for computation of a mean or standard deviation is judged to be excessively laborious and time-consuming since a large number of data samples (at 2 or more times a second) is necessary. Consequently, the measurement specifications, as exemplified in Figure 5.3, are suitable for (1) defining software for digital computer measurement processing, or (2) manual processing procedures.

Today, HAF specifies its measurement specifications mainly by manual processing procedures. Lately, HAF has been interested in computer measurement processing. Thus, HAF should consider the measurement specifications mentioned in this section.

E. COMMUNICATION ANALYSIS

Measurement for crew performance overlays the system performance measurement thus far discussed. The performance demonstrated in A-7 or F-106 aircraft clearly involves only one man; however, the same mission may be flown by two men in the F-4 aircraft, requiring additional measurement to

investigate crew interaction and diagnose individual performance contributions. The combat airlift mission in the C-130 and C-141 aircraft involves such close coordination of pilots, navigators, loadmasters and engineers that it is difficult to isolate an individual's performance (even the crewmembers themselves cannot be sure of the adequacy of their performance).

An individual's performance can be assessed by relating measurement at his workstation to overall system performance; this type of measurement is subsumed under the previous measurement discussion. However, the interaction between crewmembers requires analysis of communications---presenting somewhat different requirements than system performance measurement. The following paragraphs present important topics related to crew performance measurement.

1. Communication Measurement Categories.

Communications measurement must treat at least two gross types of crew interaction: (1) information is exchanged to aid another crewmember in performing his duties (e.g., when the F-4 Weapon System Officer acts as a good "copilot"), and (2) a crewmember provides a directive role in guiding another's performance (e.g., when the F-4 Weapon System Officer provides directive commentary to the Aircraft Commander in air-air intercept). In the latter case direct links between auditory commands and system performance can be identified, allowing communication to be measured in terms of resulting performance changes.

Six categories of measurement related to information transfer were examined:

(1) Timing. Measures of information timing should relate to (a) jamming more important messages, (b) providing information at the wrong time, (c) delay in providing

information, and (d) providing information at a rate not permitting effective response by another crewmember.

(2) Accuracy. Measures of accuracy require comparison of what is said in relation to the measured situation (e.g., was altitude reported correctly?).

(3) Brevity. As radio and interphone traffic often exceed channel capacity in combat, measurement should address communication duration and comparison brevity code.

(4) Number and Frequency. Also in relation to communication brevity, the number of communications and frequency of communications can be measured.

(5) Information content. Measures of information transmitted per unit time are quite important although usually practically difficult to obtain. Other measures such as time, number and frequency are often confounded since a crewmember may convey much information in a short time or few transmissions, while another may say little in a long time or many transmissions; without knowledge of the information content it would be difficult to evaluate these situations.

(6) Performance changes. The performance changes of the vehicle, desired as a result of communicating, define measurement in terms of links between auditory data and system/mission performance data. For example, turning performance can be measured following a "hard-as-possible" direction to the pilot of an F-4 aircraft.

2. Auditory Data Processing.

A computer-assisted manual auditory processing system is required since automatic voice decoding equipment is not available. Expert personnel are therefore required to identify complex performance and to structure processing rules for data clerks who reduce data to a form allowing input into a computer.

Three auditory data processing problems imposed requirements for measurement system design:

a. Identification.

In spite of normal communications clutter, it is necessary to clearly identify who is talking, even if two transmissions are simultaneously made (jamming). Voice key circuitry is recommended to provide a digital signal indicating which crewmember is talking.

b. Synchronization.

Audio data must be synchronized with other data recording to permit relating auditory information to corresponding performance changes. Each recording device must therefore include an audio voice track.

c. Data Reduction.

Manual functions in audio data processing are unavoidable, but can be minimized through computer-assistance. Audio data playback must be accompanied by display of performance parameters, especially the parameter of TIME, to allow computer correlation of manual audio-data entry with the digital data base. A convenient means for manual data entry is a desirable feature.

These data processing problems must be considered in the design of a combat-crew training measurement system. Thus, since HAF has at most the same aircraft as the aircraft of the USAF bases from which data were gathered, HAF must apply the same concepts for the purpose of deriving combat crew performance measurement. This approach will solve its problem of continuously optimizing the combat readiness of its combat pilots. These concepts (measurements) that were discussed in this chapter are the following:

- (1) Measurement Commonality
- (2) Common Measurement
- (3) Prototype Measurement
- (4) Measurement Parameters
- (5) Measurement Descriptions
- (6) Communication Analysis

Of course, the value of experience in combat is not easily determined. History says, experienced fighter pilots have done better than inexperienced pilots in combat situations. Intuitive judgement says that the greater the experience level, the greater the chance a unit has for success.

Modern fighters are only as effective as the pilots who fly them. The HAF should continuously evaluate the need for experienced fighter pilots in the combat ready units. The price may be high, but the price of defeat in the next battle for the air may be even greater. At the end of WWI (World War I) a doctrine was written, "... if you hold the air you cannot be beaten, if you lose the air you cannot win." [Ref. 28].

So far, in order to establish criteria for combat readiness of HAF's combat pilots, we have dealt in chapter II with the principles of human performance, in chapter III with the criteria generally and their measurement, in chapter IV with the introduction of the combat-ready crew performance measurement, and finally in chapter V we derived the combat-crew performance measurement techniques.

VI. CONCLUSIONS AND RECOMMENDATIONS

The Hellenic Air Force has always been interested in keeping the highest level of performance for its combat pilots and keep up with the latest of technology achievements. Studies, as that of USAF, have always been of a great concern, for the purpose that new techniques and theories can be revealed in its benefit. In this way, HAF keeps up with the latest and increases the efficiency and effectiveness of its combat pilots. The necessity of improving training performance information of its pilots requires new methods of measuring flight crew performance during combat crew training. As we have seen in this study, criteria for combat readiness of fighter pilots are :

- (1) Parametric referent or standard of performance.
- (2) Parametric limit about the parametric standard.
- (3) System component criteria.
- (4) Test criteria.
- (5) Multidimensional in nature and represent the complete desired end result of a system.

From the examination of this and the USAF study we can conclude that:

(1) Opening a new flow of information can have a major influence on training technology. The execution of effective contemporary training, the development of new training devices, and the exploitation of powerful concepts such as adaptive training, and learner-centered instruction, all depend on information available through performance measurement.

(2) The role of performance measurement may be that of causal input, a catalyst, or a weak link in a system chain, but the net effect of better performance measurement in any case is a positive and possible revolutionary improvement.

(3) The major difficulty that stands in the way of improvements through performance measurement is that adequate performance measurement systems do not exist where needed. The present study has defined a guide for measurement in a manner permitting adaptation to specific needs and budgets.

(4) The status of combat-crew measurement and other areas of complex man-machine performance is reflected by the measurement analysis. The measurement described here reflects the critical dimensions of performance, and agrees with the measurement structure used by operational training personnel. Given this capability a number of future advances are possible. First, use of this measurement will lead to efficient interim and immediately available measurement for training. Second, improvements in the generation of optimally efficient measurement sets may be expected. Third, clarification of the relationship between objective and subjective measurement should be possible. None of these results is going to occur without an acceptable performance measurement system and appropriate experimentation.

This section is concluded with the following recommendations for future development opportunities of the HAF:

(1) To consider measurement in the context of combat-crew training.

(2) To assess measurement, that is to identify potential measurement indicated by combat-crew training personnel.

(3) To assess the constraints placed by the environment on feasible, usable measurement systems.

(4) To establish the model of instructional system development.

(5) To establish a measurement system for the operational environment.

To establish an automated measurement system that would relieve the instructor pilot, to a maximum extent, from the requirements of having to record a great deal of information manually on the basis that such activity degrades his ability to competently instruct his student.

(6) For the purpose of deriving combat-crew performance measurement to consider (a) measurement commonality, (b) prototype measurement, (c) measurement parameters, (d) measurement specifications, (e) communication analysis.

(7) If HAF has to make a choice between video/photo and digital recording approaches to measurement system design, then the video/photo recording could be chosen, as a performance measurement system, because of its low cost, information provided, flexibility and ease of use. A hybrid system combining the advantages of both is preferable to either type of recording alone. Due primarily to cost, the bulk of measurement parameters would be derived from a video/photo system, and the remainder with a small digital recording capability.

APPENDIX A

PRCTOTYPE MEASUREMENT

In this Appendix an example of prototype measurement is presented for takeoff and climb. The format used is to present a discussion together with prototype measurement, indicating through the Figure A.1 the types of information which are considered important to a description of pilot performance.

TAKEOFF & CLIMB

All aircraft takeoff and climb to a cruising altitude and configuration. Fixed-wing aircraft perform these maneuvers in basically the same way; however, at a detailed level there are distinct differences between aircraft. Thus, measurement must be tailored to each aircraft, but the general structure of such measurement may be defined so that the essential elements are constant across aircraft. The following sequence is rather basic: Takeoff roll, Rotation, Liftoff, Gear-up, Flaps-up, Climb and Level-off. The information desired within each of these flight maneuvers may also be expressed in a substantially common manner.

Conditions. To properly interpret measurements made during a particular flight, information on the conditions existing at the time are needed. The gross weight, wind direction and velocity, runway direction and length, temperature, altimeter setting, field elevation, and position of the aircraft in formation, are reference data for the evaluation of performance.

Takeoff roll. The takeoff will be assumed to begin with the application of power. The takeoff roll maneuver will be considered finished at rotation. The objective is to

TAKEOFF & CLIMB*

CONDITIONS:

Gross Wt:____ Wing:____/ Runway:____/ Temp.:____ Alt. Set.:____ Field Elev.:____ Form Pos.:____

TAKEOFF ROLL: (To power until rotation)

Power Set:____ Centerline Dev.: Min, Max, Av.
Reject Speed: Computed Heading: Min, Max, Av.
Time:____ Dist:____ Bank: R Max, L Max

ROTATION: (Nose gear off until pitch att. established)

Rot. Speed:____ Stab. Trim:____
Pitch: Rate:____ Bank:____
Final:____ Centerline Dev.:____
Overshoot:____ Heading:____

LIFTOFF: (Pos. Vert. Vel.)

Airspeed:____ Pitch:____ Bank:____ Hdg:____
Vert. Vel. After:____ Sec.:____

GEAR-UP: (Handle up until gear-up & locked)

Gear-Up Speed:____ V.V. Init.:____ V.V. Final:____
Pitch:____ Bank:____ Hdg:____

FLAPS UP: (Start up to full up) **

Trim:	B-52	On IY	IAS	PITCH	ALT	VV	TRIM
Pitch:--	Bank:	Hdg:--	Start	x	x	x	x
A/S (INIT)--	{FINAL)--	1st Pos	x	x	x	x	x
VV (INIT)--	{FINAL)--	2nd Pos	x	x	x	x	x
ALT (INIT)--	{FINAL)--	Full	x	x	x	x	x

CLIMB & LEVEL OFF: (Depends on Flight Plan)

	PWR	A/S	MACH	INIT HDG	INIT ALT	FINAL ALT	PITCH	TRIM
Accelerate	x	x	x	x	x	x	x	x
Climb A/S {#1}								
Climb MACH {#2}	x	x	x	x	x	x	x	x
Level-off (Alt-10% VV)								
(to Cruise)	x	x	x	x	x	x	x	x

* Also, mandatory communication & instances where A/C limits are exceeded.

**F-106 has no flaps

Figure A.1 Example of Prototype Measurement.

accelerate in a straight line along the centerline, or parallel to the centerline, with wings level. Power and resultant acceleration must be checked; for heavy aircraft and/or short field takeoffs, acceleration checks are formally performed. Time and distance along the runway are checked against airspeed to determine if necessary acceleration performance is lacking in the time to safely stop the aircraft. Reject speed is noted in case of an emergence. The formation flight leader must slightly reduce power to allow a margin of thrust control for other members of the flight.

Rotation. Proper rotation is normally necessary to achieve predicted takeoff performance. Rotation will be defined as the activities between the time that the nose gear lifts off the runway until the time that a stable pitch attitude is established. Stabilizer trim is important, bank angle, centerline and heading deviations should be small. Rotation should occur within 1-2 KIAS of the desired rotation speed. The rate of rotation should not be either too large or too small. A specific pitch attitude should be established without overshoot or oscillation.

Liftoff. Liftoff is a discrete event, occurring when vertical velocity is positive. At this time, the airspeed, pitch angle, bank angle, and heading are noteworthy. The vertical velocity a short time after liftoff may also be measured to indicate whether the aircraft is positively airborne, or if there is any tendency to settle back to the runway.

Gear-up. Measurement should be taken from the time that the gear handle is raised until the time that the landing gear are up and locked. The initial speed at which the gear are raised, the change in vertical velocity during the time that the gear are coming up, and pitch, bank, and heading, should be measured.

Flaps-up. Flaps-up measurement is treated in somewhat the same manner as for gear-up, for the tasks are somewhat the same: a configuration change is occurring which presents a perturbation in longitudinal control. A trim change occurs, and pitch, bank, and heading must be controlled. Normally, flaps must not be raised before a specific altitude and airspeed (but before maximum flaps speed), and during the transition to flaps-up, changes in airspeed, vertical velocity, and altitude indicate whether the maneuver is properly performed.

The B-52 presents a special measurement requirement since a specific speed schedule must be maintained as flaps are raised; in addition to airspeed, pitch angle, altitude, vertical velocity, and stabilizer trim are of interest during this period of time.

Climb and Level-off. For each aircraft, there are a number of methods for climb-out depending on the flight plan, and desires for economy or performance. It may be desirable to measure climb performance from liftoff, or to start when the aircraft is in a clean configuration. This phase may be divided into the following parts: acceleration, maintain climb airspeed (may be several increases in airspeed during the climb), maintain climb Mach number, and level-off (normally level-off begins at an altitude which is below cruise altitude by 10% of the vertical velocity). Power, airspeed, Mach, heading, initial and final altitude, pitch angle, and trim, are parameters which may be measured during each portion of climbout.

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